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Nuclear Power Plants and Residential Housing Prices

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ABSTRACT Nuclear power plants can theoretically influence property values through a number of different channels. The public perception of risk associated with the potential hazard from the operation of a nuclear reactor and the storage of nuclear waste may lead to lower bids on properties in close proximity to the plant. In contrast, workers at the plant may be less concerned with any potential hazards, and may actually value being in proximity to the workplace. Hence, one cannot *a priori* sign the distance gradient of homes in the vicinity of a nuclear power plant. In this study, a hedonic model coupled with geographic information system (GIS) techniques is used to estimate housing price surfaces around two nuclear power plants in California. The use of GIS software allows more potential influences to housing prices to be accurately incorporated than previously included in hedonic studies. Based on the evidence from the plants chosen, these findings do not support the contention that negative imagery surrounding nuclear power plants or stored nuclear waste has a significant detrimental influence on residential home prices in the immediate vicinity of these facilities.

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Introduction

Nuclear power plants can theoretically influence residential housing prices in several ways. First, negative imagery associated with these plants may reduce offer prices if buyers believe the plant poses a potential risk. Indeed, survey research has consistently shown that nuclear technologies and radioactive waste are often viewed negatively by the general public. These attitudes are based both on individual perceptions of risk associated with proximity to nuclear reactors and waste facilities, as well as on community level perceptions that nuclear facilities, either existing or planned, will negatively affect the ability to attract and retain economic activity.[1] Even if a buyer is not personally fearful of nuclear technology, he or she may offer less for a property in the vicinity of a nuclear facility if there is fear that it will reduce the rate of appreciation of the housing asset. Second, there may be positive influences associated with accessibility to the workplace for plant workers. In general, employees of nuclear facilities may feel less threatened by nuclear technology than the population as a whole (Kivimaki and Kalimo 1993) and may offer more for properties close to a plant to reduce commute times.[2] This latter influence would be stronger with greater employment at the plant. Third, most nuclear plants are contributors to the local property tax base (Metz 1994). Thus, residents within jurisdictions (i.e. school districts, counties, etc.) close to nuclear power plants may enjoy a lower property tax burden than residents in other areas. This would be likely to increase local property values in proximity to a plant if the local fiscal bundle is capitalized in the value of these properties.

Hedonic modeling can be used to determine if negative imagery translates into economic effects. The hedonic approach has its origins in the works of Lancaster (1966) and Rosen (1974) and has been used to examine property value impacts of a variety of different spatial influences, including noxious activity (Kiel and McClain 1995; Kohlhase 1991), fiscal factors (Stull and Stull 1991), crime (Thaler 1978) and air quality (Nelson 1979). Several studies also address the issue of nuclear power plants (Metz and Clark 1997; Metz et al. 1997, Clark and Nieves 1994; Folland and Hough 1991; Gamble and Downing 1982, 1986; Galster 1986; Hageman 1981; Nelson 1981). While Blomquist (1974) finds significant impacts of a coal-fired plant on residential property values and Hageman (1981) has demonstrated the theoretical influence of nuclear power plants, the evidence on the impact of nuclear facilities on residential property values is mixed. Clark and Nieves (1994) use 1980 microdata from the U.S. Census to show that wages are higher, and land rent is lower in regions with a larger number of nuclear power plants. Folland and Hough (1991) evaluate the influence of nuclear plants on agricultural land prices in nearly 500 market areas (comprised of counties) in the U.S. and find that land prices are significantly diminished by the presence of a nuclear reactor. This effect is also found to increase with the length the reactor has been operational. Both of these studies evaluate broad geographic areas, averaging 1500 square miles in the Clark and Nieves study, and nearly 3200 miles in the work by Folland and Hough. Studies which focus on more localized property markets have not found significant property value impacts. For example, Gamble et al. (1978) find no evidence of a significant distance gradient from the property to the Three Mile Island (TMI) Nuclear plant[3]. Additionally, Gamble and Downing (1982) find that the TMI accident generated no significant difference in sale prices. Indeed, the lower prices within the 0-5 mile range were found to exist as early as 1970, which predated the operation of the plant. Likewise, Nelson (1981), who also studied properties near TMI, found that neither the absolute price, nor the appreciation rate of housing prices within 3-4 miles of the plant is significantly different after the accident. Furthermore, although Nelson found evidence of a temporary decline in prices and appreciation rates when compared with a control area 100 miles away, the real estate market recovered within three months of the accident. Finally, Metz and Clark (1997) evaluate whether announcements regarding nuclear waste significantly influencing properties sold around two plants in California. They find no evidence that announcement effects regarding nuclear waste significantly influence properties sold around two plants in California.

To clarify the impact of nuclear power plants on housing prices, this study uses a hedonic model of residential sales prices and geographic information systems (GIS) techniques to investigate potential influences over a 5-year period (1990-1994). Two nuclear power plants in California are chosen for investigation because of their size, public profile and for one of the plants, a significant change in status during this period. The first plant chosen was Diablo Canyon near San Luis Obispo, owned by Pacific Gas and Electric Company. Diablo Canyon has been operational since 1985 and in 1992 underwent a license extension review to lengthen its operating life until 2025. It is a major employer in the San Luis Obispo area with a workforce averaging 1800. The utility also contributes to the local property tax base. The Diablo Canyon reactors are adjacent to the Pacific Ocean and are not visible from any of the properties in the vicinity of the plant, with a hilly coastal range coming between the plant and the surrounding area. The second plant chosen was Rancho Seco near Sacramento, owned by the Sacramento Municipal Utility District (SMUD). Rancho Seco has been closed since 1989, but since 1991 there has been an effort to transfer the spent fuel from the reactor to a recently constructed dry storage facility at the site. The plant has experienced a steady decrease in the workforce from about 500 in 1990 to less than 150 in 1995. In addition, because the plant is owned by the local municipal utility, it has not provided a property tax subsidy to local jurisdictions. The terrain around the plant is almost flat and the cooling towers from the plant can be seen from a distance of approximately ten miles in most directions.

The remainder of the paper is organized as follows. In the second section, a brief overview of the hedonic model is provided as it relates to economic and environmental activities which generate both perceived risks as well as employment effects, and then the empirical specification of the model used in this study is discussed. The third section describes the empirical findings and the final section contains concluding remarks.

The Hedonic House Price Model

A Brief Development of Hedonic Price Theory. The hedonic model views housing as a differentiated bundle of attributes, z_i, which collectively determine the value of a particular property. This attribute vector includes structural features of the property (e.g., bedrooms, bathrooms, age of the house, interior and exterior square footage) and locational attributes (e.g., amenities and disamenities, local fiscal conditions, accessibility to workplace). Assuming perfect information about the attributes of properties for both buyers and sellers in the market, and assuming transactions costs are zero, then marginal implicit prices can be derived as the partial derivative of the housing bid-price function. Urban location theory suggests that locational equilibrium in the housing market generates utility equalizing tradeoffs between proximity to the place of work and housing prices. This gives a downward sloping housing bid-price gradient[4]. Specifically, evaluating the housing quantity gradient at a fixed point in space (i.e., at some distance from the plant, u) and assuming that the price of housing (H) and other goods (X) are also fixed at that point, the utility maximizing housing bid-price gradient is derived as $d\ln P_H/du=-t/(P_H*H)$. Assuming travel cost per mile is positive ($t>0$) and positive expenditure on housing, the housing bid-price gradient is negatively sloped. This finding of a negatively sloped housing bid-price gradient with distance from the place of employment is predicated on the assumption that accessibility to the workplace is the only locational attribute of importance to the household.

When neighborhood externalities are introduced into the model, the location equilibrium condition becomes more complex. This is because the disutility of commuting, as well as the disutility of the negative externality must be introduced into the model[5]. The slope of the housing bid-price function becomes:

$$\Psi_{workers}=d\ln P_H/du=[1/(P_H*H)]*[-t+(\partial V/\partial u)/\lambda+(\partial V/\partial E*\partial E/\partial u)/\lambda] \qquad (1)$$

The first bracketed term is the inverse of the expenditure on housing. Assuming that this is nonzero and positive, the sign of the slope of the bid-housing price function depends on the sign of the second bracketed term. The term $\partial V/\partial u$ is the marginal disutility (i.e., it is expected that $\partial V/\partial u<0$) associated with another round trip mile, which is monetized by dividing it by the lagrangian multiplier, λ. The lagrangian multiplier represents the marginal utility associated with additional income. Assuming $\lambda>0$, the first term is expected to be negative. The second term, $(\partial V/\partial E*\partial E/\partial u)/\lambda$ represents the monetized value of the change in utility associated with a change in the hazard moving away from the plant. Thus, if an increase in the expected hazard decreases utility (i.e., $\partial V/\partial E<0$) and if the expected hazard decreases with distance from the plant (i.e., $\partial E/\partial u<0$) then the second term is expected to be positive.

Finally, for residents of the community who do not work at the facility, the slope of the housing bid-price function depends only on the valuation of the expected hazard, and is given by equation (2):

$$\Psi_{nonworkers}=d\ln P_H/du=[1/(P_H*H)]*[(\partial V/\partial E*\partial E/\partial u)/\lambda] \quad (2)$$

The market housing price function, which can be derived empirically from data on housing transactions, is the outer envelope of the individual housing bid-price functions of workers at the plant and nonworkers. It is expected that nonworker households will have a positively sloped housing bid-price function, whereas the sign of worker bid-price functions can be positive or negative depending on the relative importance of accessibility versus aversion to the expected hazard. However, there are two reasons why worker bid-price gradients will be more negative than those of nonworkers (i.e., $\Psi_{nonworkers}>\Psi_{workers}$). First, nonworkers by definition are unconcerned with commuting to the plant (i.e., $\partial V/\partial u=0$), and hence they are unwilling to pay an accessibility premium. Second, the risk aversion of nuclear workers to potential nuclear hazards is likely to be lower than for workers in other industries and hence the positive influence of the expected hazard (i.e., $(\partial V/\partial E*\partial E/\partial u)/\lambda$) is expected to be lower as well. For example, Kivimaki and Kalimo (1993) show that nuclear workers believe that the possibility of a serious nuclear accident is more unlikely than members of the general public. Thus, as long as worker households are able to outbid nonworker households for land anywhere in the region, they would be expected to occupy land closer to the plant.

Changes in the Shape of the Housing Price Function. Any change in the perceptions of risk relating to the plant, or changes in employment levels, should influence the shape of individual bid-housing price gradients, and hence the shape of the housing price gradient that is observed in the market. This issue is important to the current application for several reasons. First, there are two plants being investigated in this paper. As noted in the introduction, the Diablo Canyon plant has been operational throughout the study period and is a major employer in the community. Moreover, with the exception of reactor shutdowns for refueling, the operational status of the plant has not changed since it began operation in 1985. Thus, one would expect little change in the shape of the housing price gradient over the period of investigation (1990-1994). In contrast, the Rancho Seco plant was shut down in 1989 and the employment levels at the plant have steadily declined from about 500 in 1989 to less than 150 in 1994. In addition, recent action has been taken to move nuclear waste from wet storage adjacent to the reactor to a dry storage facility at the plant. Both of these events can lead to a change in the shape of the housing price gradient over time.

Model Specification. In order to determine the extent to which proximity to a nuclear power plant influences home sale prices in the vicinity of the plant, it is important to control for as many influences as possible. That is, if the bias from excluded variables in estimates of the implicit valuation of characteristics of nuclear plants is to be avoided, then other attributes which vary spatially and may be correlated with proximity to the plant need to be included in the model.

Separate hedonic models are estimated for Diablo Canyon and Rancho Seco, using ordinary least squares. Each model includes the following categories of variables.

$\ln RPRICE_k = f/(\textit{Structure, Neighborhood, City, Year, Distance-Related Nuclear})$

where the real sale price of housing (measured in logarithmic form) in market k, is a function of five vectors of determinants: *Structure, Neighborhood, City, Year,* and *Distance-Related Nuclear*. Property sales data were obtained from TRW REDI-Property and represent individual single-family residential home sales which took place between 1990 and 1994 within 25 miles of the Rancho Seco and Diablo Canyon nuclear plants. The TRW sales price data are screened to include only those properties for which sales price and address data are complete.[6] Properties which had a real sales price less than $10,000 given the likelihood that these sales are either on properties with low qualitative values that are not adequately captured by the TRW data or the transaction is not arms-length, were screened out. Other data were dropped due to missing or miscoded data. This yielded 7694 properties for the region around Rancho Seco (which contains much of the city of Sacramento), and 606 properties for the less populous Diablo Canyon sample (which contains most of San Luis Obispo).

Michaels and Smith (1990) show that there are different submarkets operating within the Boston metropolitan area. Submarkets within the Sacramento and San Luis Obispo areas are accounted for by including a number of controls. First, various structural characteristics, including building area and lot size are included in each model. Second, a variety of neighborhood features, including household income levels, were included. Finally, dummy variables for the jurisdiction in which the property is located were included to account for submarkets related to the city of residence.

USE OF GIS TOOLS. An important empirical task is to match proximity of *Neighborhood* and *Distance-Related Nuclear* variables to the individual property. To accomplish this, GIS software was used.[7] Since all property sales data have been geocoded (i.e., assigned a latitude and longitude), the distance to a specific neighborhood or nuclear characteristic, can be readily computed as long as the location of the activity is also geocoded. This is the method used for most of the variables. However, if data cannot be accurately assigned a latitude/longitude coordinate, then the characteristics are matched according to other criteria (e.g., by census tract, zip code, or school district). This is the case for the various demographic, earthquake, and school district variables.

In addition to the distance calculation capability of GIS, it is possible to assess the proximity of a group of objects to another location whether it is a point, line, or region. This function was utilized to determine, for example, the number of Superfund sites within one mile of a property and which properties were within a quarter mile of an interstate or railroad. Again, this function is dependent on all of the data being geocoded.

Precision in geocoding is crucial when distance is the measure being used to define the neighborhood characteristics of properties. Key to geocoding is the accurate recording of property and facility addresses, the accuracy of the TIGER files from the U.S. Census Bureau and correct matching of the address to the geographic files. As the accuracy of the TIGER files can vary depending on the source from which the U.S. Census Bureau acquired geographic information, it is difficult to assign an overall estimate of accuracy to the files. However, as there is no systematic bias in these data, it is believed that the use of GIS tools to match properties to spatial characteristics of the neighborhood represents a substantial improvement over simple visual matching techniques. This is for three reasons. First, it avoids errors in measurement which are inherent in the visual techniques. Second, it permits the development of much larger data sets than could be developed if manual distance calculations were required. Finally, given the increased tendency for geographic data to be geocoded, it allows for a broad range of spatial controls in the hedonic model. When empirically deriving distance gradients, it is important to control for as many spatial variables as possible to avoid biases from excluded variables.

INDEPENDENT VARIABLES. A complete list of the variables, including variable definitions, data sources, descriptive statistics, and sign predictions are reported in Table 1 (p. 513). The vector *Structure* contains characteristics of the home. Among the attributes included are the age of the house (in linear and quadratic form), the number of bedrooms, the number of full and half baths, the presence of central air conditioning, the number of stories in the structure, the number of fireplaces, and the square footage of both the building and lot.

Numerous attributes of neighborhoods (i.e., in the *Neighborhood* category) are included to account for the influence of various locational phenomena on housing markets. These factors include demographic features such as racial and ethnic mix (i.e., Asian, African-American, White, and Hispanic), median household income level, and poverty rates as proxied by the percent of households on public assistance. Other neighborhood measures related to the composition of the local housing stock (i.e., occupancy rates, owner-occupancy) are also included. To capture the influence of local hazards and annoyance factors, a proxy for ozone air pollution, proximity to interstate highways, railroads, airport activity, Superfund sites, and the earthquake risks associated with the zip code in which the property is located are included. A determination is also made as to whether properties are within five miles of military bases (i.e., Mather AFB and McClellan AFB are both in the Rancho Seco region), or a coal-fired power plant in Morro Bay, north of Diablo Canyon. The average travel time to work in the neighborhood is included to proxy access to jobs, whereas the fiscal bundle is measured by the average property tax rate and the teacher/student ratio in the local public school district. Proximity to the ocean, and also to lakes, rivers, and streams are included to capture access to scenic vistas and recreational opportunities. Finally, the population density of the census tract in which the property is located is included to capture unmeasured amenities and disamenities (e.g., remoteness, crime) correlated with density.

Dummy variables are included to capture differences in submarkets that are related to the jurisdiction in which the property is located. The Rancho Seco sample includes properties in 14 different communities, whereas the Diablo Canyon sample includes 10 communities. Note that the city dummy variables will also account for public service provision in the various jurisdictions. Four dummy variables representing the year in which the property sold (the excluded dummy category is 1990) are also included. These variables are included because the California economy experienced a significant recession beginning in 1992.

It is assumed that the perception of a safety hazard from the plant is primarily related to the distance of the property from the plant. Recall that in the absence of employment effects, the influence of distance from the potential hazard on property values, (i.e., $\partial V/\partial E * \partial E/\partial u$), is expected to be positive, since both partial derivatives are expected to be negative. To capture the influence of proximity, the distance from the plant in linear and quadratic form is included. To account for any shifts of the distance gradient over time, distance is interacted with the year dummy variables. Finally, since media attention about the plant is likely to serve as a reminder of the presence of the plant, the number of paragraphs of press coverage about the plant's operation in the dominant local newspaper[7] is included, interacted with distance to the plant. Press coverage is measured for the period between 45 days and 120 days prior to the sale. The time period for media exposure is chosen to represent a period around the time of the sale for which the media coverage is most likely to influence the offer price of the buyer. Coverage within 45 days of the sale is presumed to be after an offer has been accepted.

FUNCTIONAL FORM. Assuming that implicit prices are not constants, nonlinear forms are preferred on theoretical grounds. Although some authors suggest the use of flexible functional forms such as the Box-Cox or generalized quadratic functional form (Rasmussen and Zuehlke 1990), others have expressed concern about accuracy of implicit prices derived from flexible forms (Cassel and Mendelsohn 1985). Cropper et al. (1988) have shown that the semi-log model outperforms other forms when there is a possibility that the model is misspecified.

Although care was taken to include a wide range of structural and locational features, all of the relevant variables were certainly not included. Thus, we employ the semi-log model.

Empirical Findings

A White-test was conducted to detect the presence of heteroskedasticity, and the null hypothesis of no heteroskedasticity is rejected at the 95 percent level of confidence for each regression. White's correction is used to generate consistent estimates of the standard errors. The empirical findings are reported in Table 2, (p. 517). The independent variables explain 78 percent and 64 percent of the variation in the log of the real house price for Rancho Seco and Diablo Canyon respectively.

Structural Characteristics. Most of the structural features are of the expected sign and significant in the Rancho Seco model although fewer are significant for the Diablo Canyon regression. Interior and exterior square footage significantly increases the sales price in both models. Although an additional bedroom significantly decreases the sale price in the Rancho Seco model, this is perhaps not surprising given that it implies smaller rooms since building area is held constant. Both central air conditioning and additional fireplaces increase real housing prices in the Rancho Seco model. Multistory homes sell for lower real prices, *ceteris paribus*, than single story homes in both samples although the variable is not quite significant in the Diablo Canyon model. Finally, real housing prices decline at a decreasing rate, with age of the house. The minimum occurs between 38-39 years of age. Note, however, that neither of these variables is statistically significant in the Diablo Canyon sample.

Neighborhood, Year and City Variables Demographic variables are found to be statistically significant in the Rancho Seco model. Housing in neighborhoods with relatively higher African-American and Asian populations sells for lower prices than in those with lower minority concentrations. Not surprisingly, home prices are higher when the house is located in a census tract with a relatively high median household income and a relatively low percentage of the population on public assistance. In analyzing overall occupancy rates, the greater the percent of occupied housing units, the lower is the home price. Indeed, the variable is negative and significant for both samples. In addition, high owner-occupancy rates significantly decrease housing values in the Rancho Seco model. The rationale for these counterintuitive findings is uncertain.

Several of the annoyance factors are statistically significant, although not always with the sign that was expected. For example, an increase in the number of Superfund sites within a mile of the property in the Rancho Seco model results in a positive correlation. Note that there are very few properties which are close to Superfund sites in the Rancho Seco sample (i.e., less than 1 percent of the observations), and no such properties in the Diablo Canyon sample. These unexpected findings persist even when a five-mile impact area is assumed. Properties which are located within a quarter of a mile of an interstate highway or a railroad almost always sell at lower real prices than properties that are less proximate to these factors, although the interstate dummy variable is not significant in the Rancho Seco model. In addition, the variable which proxies airport noise is negative in both models, and significant for Rancho Seco. Although others (Beron et al. 1997) have found that earthquake risks are negatively capitalized in housing prices, our measure is negative but it is insignificant in both models. Proximity to the Mather Air Force Base significantly decreases property values for those properties in the Rancho Seco sample within five miles of the facility. Note that airport activity is controlled by the distance-weighted airport measure. Thus, the Mather proximity measure could be capturing factors related to the loss of a large employer in the area since it was announced in 1988 that Mather Air Force Base would be shut down; the facility was closed in 1993.

Consistent with the predictions of the urban location model, properties in neighborhoods with low commute times typically have higher real sale prices. Another neighborhood characteristic which tends to increase property value is proximity to the ocean. It increases value approximately 15 percent, other things equal, for properties in the Diablo Canyon sample.

Regarding the fiscal variables, school quality as proxied by the teacher-student ratio yields insignificant results whereas tax rate is negative and significant in both samples.[8] Dummy variables for the largest jurisdictions in each region (i.e., Sacramento and San Luis Obispo) were excluded from each model. Of the dummy variables for the 13 suburban jurisdictions in the Rancho Seco model, eight were positive and significant, and only one was negative and significant. Four of the suburban dummy variables were positive and significant in the Diablo Canyon model.

The effect of time on the hedonic function is modeled as an intercept shifter and a slope shifter. Although some of the coefficients are not statistically significant, one can evaluate the point estimates. Computing the time effect at the mean distance for each sample (19.2 miles for Rancho Seco and 13.6 miles for Diablo Canyon) reveals a pattern of declining real prices over the period 1990-1994 which is consistent with the deep housing recession which plagued California in the early 1990s. When compared to 1990 (the excluded category), real prices fall by 0.3, 8.6, 17.7 and 22.6 percent for the period 1991-1994 in the Rancho Seco sample. Real housing prices fell by 6.7, 20.9, 27.3, and 36.4 percent compared to 1990 for the period 1991-1994 in the Diablo Canyon sample.

Distance-Related Nuclear Variables. Recall that, theoretically, the impact of a facility that is associated with hazardous activity may be positive or negative, depending on whether the benefits of proximity to the workplace overwhelm the disutility associated with higher perceived hazards at more proximate locations. Given the high aversion to nuclear technology and radioactive waste that has been found among survey respondents (Kunreuther et al. 1988; Slovic et al. 1991; and Erikson 1994), one suspects that the disutility from proximity would lead to significantly lower property values, especially for those properties close to the shut down and highly visible Rancho Seco facility. Positive impacts are more likely at Diablo Canyon, which remains the dominant employer in the region and whose location is relatively secluded.

DIABLO CANYON FINDINGS. Recall that the distance from the plant is included in linear and quadratic form and it is interacted with the year in which the property sold to capture any shifts in the gradient over the early 1990s. Distance is also interacted with the number of paragraphs written about the plant in the dominant local newspaper. The linear distance variable for Diablo Canyon is negative and significant, whereas the quadratic term is positive although its t-score is only 1.50. Treating the coefficients on DISTANCE, and DISTSQ as point estimates gives a u-shaped distance gradient with a minimum at 23.4 miles.[9] Furthermore, additional paragraphs appearing in the newspaper around the time of the sale have a positive but statistically insignificant influence on the slope of the housing price gradient. The hedonic housing price function for Diablo Canyon is shown graphically in Figure 1. Mean values of nondistance related variables are substituted and the hedonic surface is simulated for each of the five years of the sample. The year-distance interaction terms are statistically insignificant. In addition, even treating the parameter estimates as point estimates, it is clear from Figure 1 that the slope of the hedonic housing price gradient changes very little over time. Since employment levels at the plant are relatively constant over the period in question, this finding is not surprising.

RANCHO SECO FINDINGS. Several of the individual variables in the *Distance-Related Nuclear* category are significant in the Rancho Seco samples. Again, hedonic price gradients are derived, assuming the properties have mean values for both the structural and neighborhood characteristics. The number of paragraphs written about the plant is also held constant at its mean level (i.e., approximately 43 paragraphs). The hedonic housing price surface is shown graphically in Figure 2. Like the Diablo Canyon surface, the Rancho Seco gradient is u-shaped. However, both linear and quadratic terms are statistically significant.[10] In addition, the minimum point is substantially closer to the plant (11.4 miles). Finally, note that the gradient is becoming significantly more negative over time with the distance-year interaction terms negative and significant for the period 1992-1994, which causes the minimum point of the gradient to increase. By 1994 the minimum point increased to 13.4 miles.

The finding of a u-shape for the gradient is surprising in light of the small and declining employment levels at the plant and given the visibility of the plant from the surrounding area. Rather, one would suspect that any "geographic footprint"

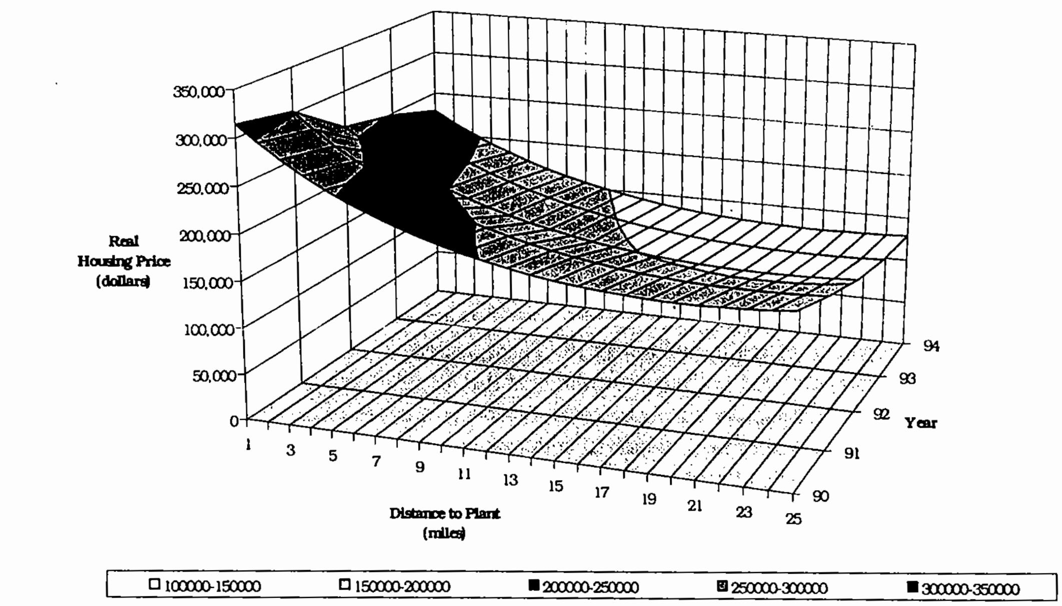

Figure 1. Housing Price Gradient, Diablo Canyon

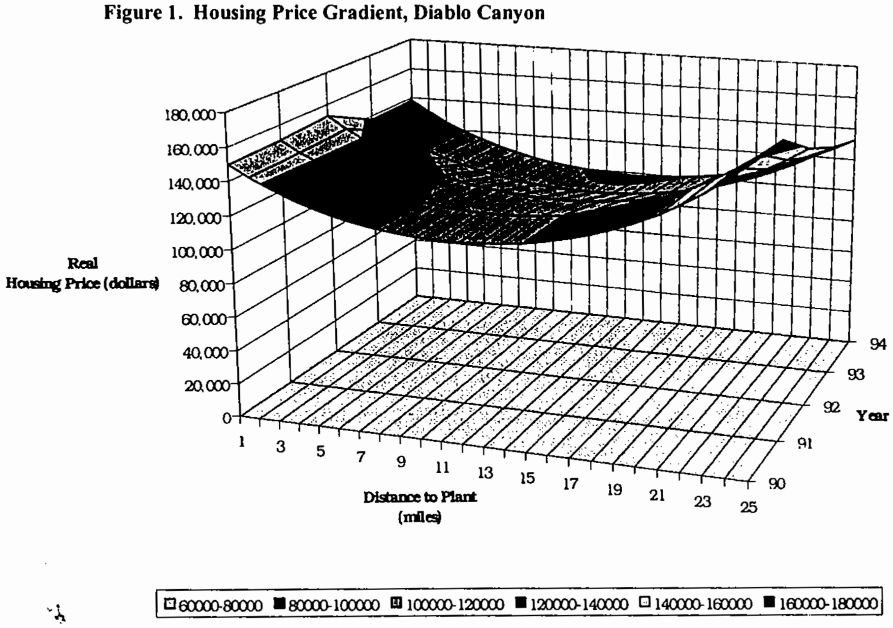

Figure 2. Housing Price Gradient, Rancho Seco

that the plant might have on local real estate markets would reflect the disamenity associated with proximity to a local hazard (i.e. nuclear waste). In addition, theory would suggest that the minimum point should be moving closer to the plant, rather than further away, if employment effects are declining. These findings suggest reduced aversion to the facility over time even though the volume of waste currently stored at the plant has not changed. We suspect that the there are a number of possible factors which account for the attractiveness of proximity to the plant. First, the area surrounding Rancho Seco is relatively uncongested. Although population density is controlled for, it is possible that this is a poor proxy for this amenity. Second, the fact that the plant has been shut down may confer a sense of safety upon nearby residents since no nuclear power is being generated and no additional waste is being produced. Third, there are several recreational activities which are available at the Rancho Seco site. SMUD, which owns the Rancho Seco Plant, operates 433 acres of the 2480 acre Rancho Seco site as a park and lake complex which includes group campgrounds, group and family picnic areas, and swimming and fishing opportunities. Fourth, since the shutdown of Rancho Seco, SMUD officials have investigated several options concerning the transition of the plant and property. A draft master plan issued in January 1994 called for the expansion of the park to 1600 acres. The proposed recreational development includes a public golf course, equestrian center, wetlands preserve, a nature center, and hiking trails (Sacramento Municipal Utility District 1994). Finally, SMUD officials have begun the process of moving nuclear waste from wet storage in the reactor building to a dry-storage facility at the site. Dry storage may be viewed by the public as being a less hazardous technology than wet storage. If residents see the transition at the Rancho Seco site as either reducing a hazard or creating better recreational activities, then a steeper gradient would be expected.

Concluding Remarks

Significant political debate exists at the local, state, and federal levels regarding the perceived risks, stigma, and negative imagery that are claimed to accompany nuclear power plants, and the storage and permanent disposal of spent nuclear fuel. Often cited in the debate is the large volume of local, regional, and national survey data that has been collected on public opinion regarding proximity to nuclear facilities. These surveys often reveal a high percentage of respondents who, when given a choice, consistently express an unwillingness to live, visit, or operate a business near nuclear related facilities. Based on evidence from the two California plants studied, we conclude that any negative imagery associated with nuclear power plants or stored nuclear waste does not translate into a significant detrimental influence on residential home prices in the immediate vicinity of the facilities studied.

The findings at Diablo Canyon suggest a housing price premium until the household is about 23 miles from the plant. While we have been careful to account for a wide range of neighborhood factors (indeed our model explains approximately 64 percent of the variation in real housing prices), it is possible that we have omitted some important locational influence which is being captured in the distance variable. For example, the region near the plant is less urban, and offers more remoteness to residents. However, it is clear than any negative property value impacts resulting from perceived risks associated with the plant do not overwhelm accessibility and other desirable attributes which are correlated with proximity to Diablo Canyon.

For the Rancho Seco plant, which is no longer operating and which is more visible than the Diablo Canyon plant, residential home prices actually rise with proximity to the plant for those properties closest to the plant (within 11 miles). Furthermore, aversion to the plant appears to be declining as the minimum point has moved nearly two miles further from the plant over the five years of the study even though plant employment has continually declined. We suspect that the fact that the plant is now shut down, combined with the relatively uncongested nature of the general area and the recreational opportunities that exist in the vicinity of the plant overwhelm any detrimental impact resulting from the nuclear waste that remains stored at Rancho Seco.

A major challenge for policy makers in their efforts to site temporary and permanent nuclear waste facilities and select routes for nuclear waste transportation is the need to balance survey evidence, that suggests that adverse economic impacts and stigmatization are likely to result, with findings of multivariate analyses, that suggest that any risk perceptions that exist may not be reflected in local economic behavior. Indeed, our research suggests that some individuals may actually be likely to place premiums on proximity to nuclear plants. Policy initiatives that attempt to anticipate public reaction and behavior with regard to nuclear waste facility siting options based only on research on stated intent and imagery would therefore likely overestimate the extent of the reaction in the local economies concerned. The political and economic environments in which nuclear waste facility siting decisions are made may indeed be ones in which there are no permanent accompanying negative economic effects, but in which there is significant political opposition. Only when policy makers and planners are able to respond knowledgeably on the basis of both survey data and studies using multivariate analyses will they be able to generate greater public dialogue, public acceptance, and political approval.

NOTES

1. In the survey literature, see Kunreuther et al. (1988); Slovic et al. (1991); and Erikson (1994). See also Allison and Calzonetti (1992) and Metz (1994).
2. For example, in a survey of scientists and engineers, Barke and Jenkins-Smith (1993) find that perceptions of risks toward nuclear technology are significantly associated with the type of institution in which the scientist is employed. In addition, life scientists tend to

perceive higher risks associated with nuclear energy and nuclear waste management than physicists, chemists and engineers.

3. Note that Gamble et al. acknowledge that the substantial property tax subsidy may influence these findings. That is, positive capitalization from a lower property tax burden may overwhelm any negative capitalization from risks or other attributes of the plants. In our empirical modeling we avoid this potential bias by including adequate controls for the local fiscal bundle for residential housing.
4. Assume that households maximize utility, V(X,H) which is a function of a vector of nonhousing goods, X, and a housing good, H. Households choose optimal levels of X and H subject to a budget constraint that includes expenditures on nonhousing goods (P_X*X); expenditures on housing (P_H*H); and out-of-pocket expenditures on commuting (t*u) where t = commuting cost of a mile spent commuting, and u = number of round-trip miles to work. Thus, the budget constraint is defined as $I=P_X*X+P_H*H+t*u$. Notice that there is no disutility associated with time spent commuting in this simple model. Rather, commuting enters the optimization through the budget constraint only (Muth 1969). The locational equilibrium condition is derived by taking the first derivative of the lagrangian function ($L=V(X,H)+\lambda(I-P_X*X-P_H*H-t*u)$) with respect to u, and setting that function equal to zero.
5. Now the household utility function is, V(X,H,E(u),u). Thus, utility is now also a function of the expected hazard associated with the facility (E) which is perceived by residents to decline with distance from the facility (i.e., $\partial E/\partial u<0$). Utility also depends directly on distance from the plant. The budget constraint is defined as before (i.e., $I=P_X*X+P_H*H+t*u$). Again, the locational equilibrium condition is derived by taking the partial derivative of the lagrangian function ($L = V(X,H,E(u),u)+\lambda(I-P_X*X-P_H*H-t*u)$ with respect to u, and setting that function equal to zero.
6. TRW REDI Property Data obtained the data from yearly county tax rolls which are merged with weekly new deed reports from the county recorder's office. Additional information (e.g., structural characteristics) about the properties is obtained from various appraisal groups, as not all counties obtain the same level of detailed information on the properties. In the state of California there are two situations which would result in a property sale not being included in the TRW REDI data set: (1) A specific request for non-disclosure by the owner (usually a well known individual who would not want the public to know the price of the property) and; (2) The sales tax information (from which the price is calculated) is not located on the first page of the recorder's document which is the source of information for TRW REDI-Property. While the first situation is likely to systematically undercount high priced properties, TRW has indicated that the second situation is unlikely to introduce systematic bias into the sample. TRW estimates that 46% of the approximately six million residential properties had sales tax data.
7. PC-based GIS software packages from MapInfo and Scan/US have been used in this project.
8. The *Sacramento Bee* is the primary local newspaper in the Sacramento metropolitan area, and the *Telegram-Tribune* is the dominant paper in the San Luis Obispo region.
9. It should be noted that the property tax rate is the actual tax burden for the property, since it reflects the ratio of the taxes paid to the assessed valuation. Thus, any tax subsidy from the Diablo Canyon plant is incorporated in the measure.
10. Although the variable COMMUTE may proxy travel time to the plant, we believe that it is primarily measuring proximity to San Luis Obispo. For the entire sample, the correlation between commuting time and distance from Diablo Canyon is low (0.29) but it is substantially higher and negative (-0.86) for homes within 10 miles of the plant. Moreover, dropping COMMUTE does significantly alter the findings on the distance

variables. Specifically, DISTANCE becomes insignificant with a t-score below one, and DISTSQ also has a very low t-score. We believe that if COMMUTE is left out of the model, then DISTANCE proxies both proximity to the plant, and distance from the city. This is especially true given that the region is geographically a half circle, with the plant at the center and the ocean to the west. Hence, we believe that it is preferable to keep the COMMUTE variable in the model.

11. We also experimented with higher order polynomial terms. When we included a cubic term to allow for a second turning point, the linear, quadratic and cubic terms became insignificant.

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TABLE 1: VARIABLE DESCRIPTION, SIGN EXPECTATION, MEAN VALUE AND STANDARD DEVIATION

Variable Name	Definition	Source	Sign	Mean Values	σ
Dependent Variable and Variables in the *Structure* Category					
LRPRICE	Natural log of the real sale price of the property (1990 $)	TRW nominal price divided by the national CPI for housing.		RS = $130,821 (Rancho Seco) DC= $170,076 Diablo Canyon) (Note: mean values are shown for actual real sale price)	RS =$59,083 DC= $68,019
AGEHOUSE	Age of house in years	TRW	?	RS= 19.342 DC = 22.977	RS= 21.259 DC= 14.429
AGESQ	Age of house in years squared	Computed	?	RS= 825.981 DC= 735.779	RS= 1449.487 DC= 979.130
BEDROOM	Number of bedrooms in house	TRW	+	RS= 3.116 DC= 2.777	RS= 0.717 DC= 0.674
BLDGAREA	Size of the residence in square feet	TRW	+	RS= 1528.346 DC= 1424.025	RS= 510.943 DC= 502.693
CNTRLAIR	1 = presence of central air conditioning, 0 otherwise	TRW	+	RS= 0.691 DC= -------	RS= 0.462 DC= -------
FIREPLACE	Number of fireplaces in the residence	TRW	+	RS= 0.868 DC= 0.698	RS= 0.435 DC= 0.569
FULLBATH	Number of full bath-rooms in the home	TRW	+	RS= 1.894 DC= 1.756	RS= 0.581 DC= 0.523
HALFBATH	Number of half bath-rooms in the home	TRW	+	RS= 0.148 DC= 0.148	RS= 0.355 DC= 0.365
LOTAREA	Size of the lot in square feet	TRW	+	RS= 10305.90 DC= 16541.19	RS= 29351.62 DC= 82485.13
NUMSTORY	Number of stories in the house.	TRW	?	RS= 1.199 DC= 1.007	RS= 0.432 DC= 0.533
Variables in the *Neighborhood* Category					
AIRPORT	Distance weighted value of airport activity (i.e., number of operations at airport divided by distance of airport to the property.	FAA & MapInfo Computed	-	RS= 25055.73 DC= 22926.64	RS= 36901.54 DC= 23250.11
COALPLANT	Dummy variable=1 if property is within 5 miles of Morro Bay Power Plant; 0=otherwise.	MapExpert & MapInfo Computed	?	RS= -------- DC= 0.361	RS= --------- DC= 0.481

Variable Name	Definition	Source	Sign	Mean Values	σ
COMMUTE	Average travel time of households living in that census tract.	Census STF-3A 1990	-	RS= 24.632 DC= 19.705	RS= 3.618 DC= 2.466
EARTHQK	Earthquake classification of the zip code where the property is located. (Left out dummy is always lowest risk classification). 1 if moderate risk, 0 if low risk for RS; 1 if high risk, 0 if moderate risk for DC	Risk Mgmt. Associates study prepared for Freddie Mac	-	RS= 0.027 DC= 0.272	RS= 0.163 DC= 0.445
INCOME	Median household income of census tract where property is located	Census STF -3A 1990	+	RS= 38912.49 DC=32612.84	RS= 10835.41 DC= 5023.412
INTERSTATE	1= interstate highway within 0.25 miles of property, 0 otherwise.	Census TIGER database (MapInfo computed 1992)	-	RS= 0.065 DC= 0.193	RS= 0.246 DC= 0.395
MCLELLAN	Dummy variable=1 if property is within 5 miles of McClellan AFB; 0=otherwise.	FAA & MapInfo Computed	?	RS= 15.726 DC= --------	RS= 7.627 DC= -------
MATHER	Dummy variable=1 if property is within 5 miles of Mather AFB; 0=otherwise.	FAA & MapInfo Computed	?	RS= 11.682 DC= --------	RS= 5.824 DC= -------
OCEAN	1 if property within .25 miles of ocean	Census TIGER database (1992) MapInfo Computed	+	RS= ------ DC= 0.112	RS= ------- DC= 0.316
OZONE	Distance weighted value of the nearest ozone monitor; the ozone concentration divided by the distance of the monitor to the property.	EPA-AIRS AQS Database	-	RS= 1.893 DC=1.816	RS= 4.142 DC= 1.631
%ASIAN	Percent of the census tract population that is Asian or Pacific Islander.	Census STF-3A 1990	?	RS= 12.577 DC= 3.200	RS= 8.513 DC= 2.408
%AFAMER	Percent of the census tract population that is African American.	Census STF-3A 1990	?	RS= 9.921 DC= 1.022	RS= 10.105 DC= 0.742
%HISPANIC	Percent of the census tract population that is of Hispanic origin.	Census STF-3A 1990	?	RS= 13.285 DC= 9.552	RS= 6.600 DC= 8.953
%OWNEROCC	Percent of the census tract occupied housing units that are owner occupied.	Census STF-3A 1990	+	RS= 71.061 DC= 55.562	RS= 16.958 DC= 12.767

Variable	Definition	Source	Sign	Mean Values	σ
%OCCUNIT	Percent of the census tract housing units that are occupied	Census STF-3A 1990	+	RS= 93.022 DC= 91.420	RS= 4.000 DC= 7.224
%PUBASST	Percent of the census tract population that is on public assistance	Census STF-3A 1990	-	RS= 10.497 DC= 6.381	RS= 8.876 DC= 2.960
POPDENSITY	Population density of census tract where property is located	Census STF-3A 1990	?	RS= 2497.321 DC= 2257.071	RS=3609.454 DC= 5543.101
RAILROAD	1= railroad tracks within 0.25 miles of property. 0 otherwise.	Census TIGER database MapInfo computed (1992)	-	RS= 0.170 DC= 0.084	RS= 0.376 DC= 0.278
SUPERFUND	Number of sites which are on the National Priority List (i.e., Superfund site), within 1 mile of the property. [Abandoned, inactive and uncontrolled hazardous waste sites]	EPA, Office fice of Solid Waste & Emerg. Response: Landview II CERCNPL Database (1993)	-	RS= 0.003 DC= -------	RS= 0.056 DC= -------
TAXRATE	1994 tax payment divided by 1994 assessed valuation	TRW	?	RS= 0.011 DC= 0.011	RS= 0.002 DC= 0.001
TSRATIO	The student teacher ratio for the secondary or unified school district in which the property is located.	CA State Dept of Ed. Online Data Service	+	RS= 0.041 DC= 0.044	RS= 0.003 DC= 0.004
WATER	1 if property within .25 miles of lake, river or stream.	Census TIGER database (1992) MapInfo Computed	+	RS= 0.320 DC= 0.407	RS= 0.506 DC= 0.492

Variables in the *City* Category

Variable	Definition	Source	Sign	Mean Values	σ
City Dummy Variables	Suburban communities in the Rancho Seco region include Acampo, Courtland, Elk Grove, Folsom, Galt, Herald, Lockeford, Lodi, Sloughhouse, Stockton, Wilton, Walnut Grove, Woodbridge. Suburban communities in the Diablo Canyon region include Atascadoro, Cayucos, Grover Beach, Los Osos, Morro Bay, Nipomo, Pismo Beach, Santa Maria, Templeton	TRW	?	Acampo (0.001) Courtland (0.000) Elk Grove (0.191), Folsom (0.066), Galt (0.027), Herald (0.001), Lockefd (0.004) Lodi (0.064), Sloughse (0.006), Stockton (0.004),	Acampo (0.032) Courtlnd (0.019) Elk Grve (0.393), Folsom (0.247), Galt (0.027), Herald (0.001), Lockefd (0.004) Lodi (0.064), Sloughse (0.006), Stockton (0.004),

Variables in the *City* Category (cont'd)

Variable	Definition	Source	Sign	Mean Values	σ
				Wilton (0.006),	Wilton (0.006),
				Walnut G (0.000),	Walnut G(0.030)
				Woodbrdge (0.006)	Woodbrdge (0.079)
				Atascado.(0.249),	Atascado. (0.432)
				Cayucos (0.010),	Cayucos (0.099)
				Grover Bch (0.053),	Grover Bch(0.224)
				Los Osos (0.259),	Los Osos (0.438)
				Morro Bay (0.097),	Morro Bay (0.297)
				Nipomo(0.030),	Nipomo (0.170)
				Pismo Bch. (0.054),	Pismo Bch.(0.227)
				St Maria (0.011),	St Maria (0.011)
				Templeton (0.013)	Templeton (0.114)

Variables in the *Year* Category

YEAR91	1 if property sold in 1991	TRW	?	RS= 0.153 DC= 0.087	RS= 0.360 DC= 0.283
YEAR92	1 if property sold in 1992	TRW	?	RS= 0.171 DC= 0.127	RS= 0.377 DC= 0.333
YEAR93	1 if property sold in 1993	TRW	?	RS= 0.213 DC= 0.318	RS= 0.409 DC= 0.466
YEAR94	1 if property sold in 1994	TRW	?	RS= 0.232 DC= 0.365	RS= 0.422 DC= 0.482
DISTSQ	Distance squared	Computed	?	RS= 383.157 DC= 217.720	RS= 131.382 DC= 175.033
DISTANCE	Distance to the plant from the property.	MapInfo Computed	?	RS= 19.247 DC= 13.568	RS= 3.564 DC= 5.804
DISTXPAR	Total number of paragraphs in articles written about the facility in the period 120 days and 45 days prior to the sale interacted with the distance of the property from the plant.	Sacramento Bee, MapInfo computed	?	RS= 831.099 DC= 3808.999	RS= 832.897 DC= 2291.797
DISTXY91 DISTXY92 DISTXY93 DISTXY94	Distance of property from the plant interacted with the year in which the property is sold, for years 1991-1994.	MapInfo computed	?	RS_{91}= 2.997 RS_{92}= 3.261 RS_{93}= 4.047 RS_{94}= 4.415 DC_{91}= 1.114 DC_{92}= 1.611 DC_{93}= 4.463 DC_{94}= 4.937	RS_{91}= 7.192 RS_{92}= 7.339 RS_{93}= 7.964 RS_{94}= 8.224 DC_{91}= 3.939 DC_{92}= 4.726 DC_{93}= 7.333 DC_{94}= 7.377

TABLE 2: HEDONIC HOUSING PRICE FUNCTION

Dependent Variable: Log of Real Sale Price					
Rancho Seco Sample			Diablo Canyon Sample		
Variable	Coefficient	t-score	Variable	Coefficient	t-score
Intercept	12.80981**	50.850	Intercept	15.92051**	13.579
Structural Characteristics					
BLDGAREA	0.000452**	45.572	BLDGAREA	0.000367**	9.379
LOTAREA	7.85E-07**	4.787	LOTAREA	2.05E-07 *	1.759
BEDROOM	-0.009073*	-1.655	BEDROOM	-0.059460	-1.578
FULLBATH	0.011622	1.296	FULLBATH	0.048329	1.467
HALFBATH	0.005964	0.630	HALFBATH	-0.010751	-0.430
CNTRLAIR	0.029045**	4.073	--------------		
FIREPLACE	0.069543**	9.778	FIREPLACE	0.027144	1.496
NUMSTORY	-0.045822**	-5.722	NUMSTORY	-0.026081	-1.511
AGEHOUSE	-0.003686**	-6.400	AGEHOUSE	-0.002436	-0.949
AGESQ	4.75E-05**	6.429	AGESQ	3.24E-05	0.878
Neighborhood Characteristics					
%ASIAN	-0.000633	-1.252	%ASIAN	0.007147	0.651
%AFAMER	-0.005247**	-9.974	%AFAMER	-0.047043	-0.963
%HISPANIC	-0.009448**	-15.766	%HISPANIC	-0.007403	-1.442
INCOME	2.06E-06**	2.670	INCOME	3.52E-06	0.665
%PUBASST	-0.006879**	-8.376	%PUBASST	-0.001081	-0.114
%OCCUNIT	-0.006022**	-6.453	%OCCUNIT	-0.019665**	-2.664
%OWNEROCC	-0.000863**	-2.757	%OWNEROCC	0.000162	-0.058
OZONE	-0.000838*	-1.814	OZONE	-0.005925	-0.542
INTERSTATE	-0.013887	-1.196	INTERSTATE	-0.149748**	-4.370
RAILROAD	-0.015913**	-2.322	RAILROAD	-0.066662*	-1.881
SUPERFUND	0.117320*	1.759	--------------		
AIRPORT	-4.38E-07**	-3.313	AIRPORT	-6.41E-07	-1.048
--------------			COALPLANT	0.160178	0.992

TABLE 2 (CONTINUED): HEDONIC HOUSING PRICE FUNCTION

Variable	Coefficient	t-score	Variable	Coefficient	t-score
***Neighborhood Characteristics** (continued)*					
MATHER	-0.088257**	-3.360	---------------		
MCLELLAN	0.019203	0.625	---------------		
EARTHQK	-0.021537	-1.389	EARTHQK	-0.293889	-1.393
WATER	0.001813	0.362	WATER	-0.050448	-1.531
---------------			OCEAN	0.147352**	2.428
TSRATIO	-4.065770	-0.986	TSRATIO	-1.013095	-0.076
TAXRATE	-5.454212**	-2.381	TAXRATE	-17.95548**	-2.032
COMMUTE	-0.021681**	-10.975	COMMUTE	-0.073967**	-4.092
POPDENSITY	-2.98E-06**	-3.142	POPDENSITY	-2.60E-06	-0.788
City Dummy Variables					
ACAMPO	0.234412**	2.521	ATASCADORO	0.334426**	2.133
COURTLAND	-0.175597	-1.075	CAYUCOS	-0.017753	-0.055
ELKGROVE	0.106846**	14.724	GROVERBEACH	0.274942*	1.765
FOLSOM	-0.055195**	-3.112	LOSOSOS	0.012936	0.354
GALT	0.206517**	2.739	MORROBAY	-0.244236	-1.294
HERALD	0.029701	0.230	NIPOMO	0.698559**	3.303
LOCKEFORD	0.165921**	4.964	PISMOBEACH	0.109952*	1.687
LODI	0.083013**	3.810	SANTAMARIA	0.796291**	2.183
SLOUGHHOUSE	0.286838**	6.990	TEMPLETON	0.261226	1.198
STOCKTON	-0.055667	-0.917			
WILTON	0.336289**	6.796			
WALNUTGROVE	0.081571	0.919			
WOODBRIDGE	0.102099**	4.235			
Year Dummy Variables					
YEAR91	0.006034	0.115	YEAR91	-0.022122	-0.198
YEAR92	0.025423	0.498	YEAR92	-0.205191*	-1.771
YEAR93	-0.078647*	-1.652	YEAR93	-0.241395**	-2.118
YEAR94	-0.070302	-1.392	YEAR94	-0.349659*	-1.902

Table 2 (continued): Hedonic Housing Price Function

Distance-Related Nuclear Variables					
DISTANCE	-0.051774**	-3.847	DISTANCE	-0.077131**	-2.008
DISTSQ	0.002227**	6.664	DISTSQ	0.001649	1.499
DIST×PAR	3.68E-06	1.179	DIST×PAR	9.52E-06	1.502
DIST×Y91	-0.000493	-0.178	DIST×Y91	-0.003321	-0.512
DIST×Y92	-0.005816**	-2.107	DIST×Y92	-0.000316	-0.053
DIST×Y93	-0.005136**	-1.977	DIST×Y93	-0.002343	-0.393
DIST×Y94	-0.008083**	-2.981	DIST×Y94	-0.001103	-0.125
N. Obs. = 7694	$R^2_{Adjusted}$ = 0.78	F-statistic = 516.57**	N. Obs.= 606	$R^2_{Adjusted}$ = 0.64	F-statistic = 23.91**

* Significant at 90% level of confidence in two-tailed test

** Significant at 95% level of confidence in two-tailed test.